DOCUMENT RESUME

ED 214 948 TM 820 081

AUTHOR Lord, Frederic M.
TITLE The Standard Error of Equipercentile Equating.
INSTITUTION Educational Testing Service, Princeton, N.J.
SPONS AGENCY Office of Naval Research, Arlington, Va. Personnel and Training Research Programs Office.
REPORT NO ETS-RR-81-48
PUB DATE Nov 81
CONTRACT ONR-N00014-80-C-0402
NOTE 32p.

EDRS PRICE MF01/PC02 Plus Postage.
DESCRIPTORS Educational Testing; *Equated Scores; *Error of Measurement; *Mathematical Formulas; Sampling; Testing Problems
IDENTIFIERS *Equipercentile Equating; Monte Carlo Methods

ABSTRACT

Transformations or equating of raw test scores on two or more forms of the same test are made interchangeable by empirical procedures deriving the standard error of an equipercentile equating for four different situations. Some numerical results are checked by Monte Carlo methods. Numerical standard errors are computed for two sets of real data. (Author/CM)

****
* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *
****

ED214948

RR-81-48

THE STANDARD ERROR OF EQUIPERCENTILE EQUATING

Frederic M. Lord

U.S. DEPARTMENT OF EDUCATION
NATIONAL INSTITUTE OF EDUCATION
EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)

☒ This document has been reproduced as received from the person or organization originating it.

☐ Minor changes have been made to improve reproduction quality.

• Points of view or opinions stated in this document do not necessarily represent official NIE position or policy.

"PERMISSION TO REPRODUCE THIS MATERIAL HAS BEEN GRANTED BY

The Office of Naval Research

TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)."

This research was sponsored in part by the Personnel and Training Research Programs Psychological Sciences Division Office of Naval Research, under Contract No. N00014-80-C-0402

Contract Authority Identification Number NR No. 150-453

Frederic M. Lord, Principal Investigator

Educational Testing Service

Princeton, New Jersey

November 1981

Reproduction in whole or in part is permitted for any purpose of the United States Government.

Approved for public release; distribution unlimited.

TM 820 081

THE STANDARD ERROR OF EQUIPERCENTILE EQUATING

Frederic M. Lord

This research was sponsored in part by the
Personnel and Training Research Programs
Psychological Sciences Division
Office of Naval Research, under
Contract No. N00014-80-C-0402

Contract Authority Identification Number
NR No. 150-453

Frederic M. Lord, Principal Investigator

Educational Testing Service

Princeton, New Jersey

November 1981

Reproduction in whole or in part is permitted
for any purpose of the United States Government.

Approved for public release; distribution
unlimited.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) The Standard Error of Equipercentile Equating		5. TYPE OF REPORT & PERIOD COVERED Technical Report 6. PERFORMING ORG. REPORT NUMBER Research Report 81-48
7. AUTHOR(s) Frederic M. Lord		8. CONTRACT OR GRANT NUMBER(s) N00014-80-C-0402
9. PERFORMING ORGANIZATION NAME AND ADDRESS Educational Testing Service Princeton, NJ 08541		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NR 150-453
11. CONTROLLING OFFICE NAME AND ADDRESS Personnel and Training Research Programs Office of Naval Research (Code 458)		12. REPORT DATE November 1981 13. NUMBER OF PAGES 17
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Equating, Standard Error, Order Statistics, Quantiles, Mental Tests

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The standard error of an equipercentile equating is derived for four different situations. Some numerical results are checked by Monte Carlo methods. Numerical standard errors are computed for two sets of real data.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

S/N 0102-LF-014-6601

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

The Standard Error of Equipercentile Equating

Abstract

The standard error of an equipercentile equating is derived for four different situations. Some numerical results are checked by Monte Carlo methods. Numerical standard errors are computed for two sets of real data.

The Standard Error of Equipercentile Equating*

It is frequently desired to use scores on two or more forms of the same test interchangeably. If the test forms differ in difficulty or in other ways, some transformation of the raw test scores must be made to adjust for these differences. Transformations that (attempt to) make scores on different forms interchangeable are called equatings. In equipercentile equating, these transformations are determined by the requirement that for some specified population, the cumulative frequency distribution of the transformed scores shall (theoretically) be the same regardless of the test form administered.

In practice, some empirical procedure is used to implement this theoretical definition for an actual sample of examinees. Sampling fluctuation in the resulting empirical equating is the subject of concern here.

Consider the following empirical large-sample equipercentile equating procedure:

1. Administer tests X and Y to N examinees. Score both tests.

2. Given any fixed x_o, find the score y' that has the same sample cumulative frequency.

3. Assert that the scores (x_o, y') are asymptotically equated. (This procedure is slightly biased since Nq observations lie below x_o and only $Nq - 1$ observations lie below y'. We ignore this, since it will not affect the asymptotic variance.)

---

*This work was supported in part by contract N00014-80-C-0402, project designation NR150-453 between the Office of Naval Research and Educational Testing Service. Reproduction in whole or in part is permitted for any purpose of the United States Government.

We must now find the asymptotic sampling variance of this y' for fixed x_o. We will consider first a (unrealistic) case where the test score is a continuous variable, then a more usual case where the test score is nonnegative integer.

If tests X and Y are given to the same examinees, there is likely to be a practice effect or a fatigue effect on the second test administered. To avoid this, it is common to give tests X and Y to different random samples from the same population of examinees. We consider this case first.

1. Continuous Case, Two Groups

Let $F(x)$ and $G(y)$ denote the cumulative frequency distribution of score x and score y in the population. We administer test X to a sample of N_1 examinees and find that in the sample a proportion q of these fall below the chosen fixed value x_o. Having administered test Y to a sample of N_2 examinees from the same population, we denote the q-th order statistic in this sample by y' and assert that y' is equivalent (equated) to x_o. We wish to find the asymptotic sampling variance of y' (it is always to be understood that x_o is fixed).

For fixed q, y' is asymptotically normally distributed with mean $\mu_{y'|q}$ determined by the relation

$$G(\mu_{y'|q}) = q \tag{1}$$

and variance

$$\sigma^2_{y'|q} = pq/N_2(g(\mu_{y'|q}))^2 \quad , \tag{2}$$

where $p \equiv 1 - q$ and $g(y)$ is the probability density at y (Kendall & Stuart, 1969, Sections 14.11-14.12). When q is random, a well-known identity gives

$$\text{Var } y' \equiv \text{Var}(\mu_{y'|q}) + \mathcal{E}(\sigma^2_{y'|q}) \quad . \tag{3}$$

From (1)

$$\frac{d}{dq}\mu_{y'|q} = \frac{1}{g(\mu_{y'|q})} \quad .$$

By the delta method, we find

$$\text{Var}(\mu_{y'|q}) = PQ/N_1 g_o^2 \tag{4}$$

where Q is defined by

$$Q \equiv F(x_o) \quad , \tag{5}$$

$P \equiv 1 - Q$, $g_o \equiv g(y_o)$, and y_o is defined by

$$G(y_o) \equiv Q \quad . \tag{6}$$

To evaluate $\delta\sigma^2_{y'|q}$ we rewrite (2), expand in series, and neglect higher order terms:

$$\delta\sigma^2_{y'|q} = \delta \frac{pq}{N_2 g_o^2 (1 - \frac{g - g_o}{g_o})^2}$$

$$\equiv \delta \frac{pq}{N_2 g_o^2} (1 - 2 \frac{g - g_o}{g_o} + \dots)$$

$$\cong \delta \frac{p - p^2}{N_2 g_o^2} = \frac{1}{N_2 g_o^2} (p - \text{Var } p - P^2) \cong \frac{PQ}{N_2 g_o^2} \qquad (7)$$

where $g \equiv g(\mu_{y'|q})$. Substituting (4) and (7) into (3) we have finally

$$\text{Var } y' \cong \frac{PQ}{g_o^2} \left(\frac{1}{N_1} + \frac{1}{N_2} \right) \quad . \qquad (8)$$

2. Discrete Case, Two Groups

Consider next the case where scores x and y are nonnegative integers. For convenience, we will always pick x_o to be an integer plus 0.5. Let $F(x)$ and $G(y)$ be distribution functions continuous to the right of each integer and let y_o be the integer defined by the relation $G(y_o - 1) < Q \equiv F(x_o) \leq G(y_o)$. It will ordinarily be

asymptotically infinitely unlikely that $G(y_o) = Q$; for simplicity, we will assume hereafter that $G(y_o) > Q$.

If we now define y' as in the preceding section, we are sure that integers y' and y_o will be equal for sufficiently large N . This means to the usual order of approximation that y' will have an asymptotic variance of zero. Let us use linear interpolation to define a value y'' as follows:

$$y'' = y' - 0.5 + \frac{q - \hat{G}^-}{\hat{g}} \tag{9}$$

where $\hat{G}^-$ is the observed proportion of Y scores <u>below</u> the integer y' and $\hat{g}$ is the observed proportion of scores at y' . We will in the discrete case assert that y'' is equated to x_o . It is the asymptotic variance of y'' that is now required.

As noted above, the variance of y' is asymptotically zero. The proportions q , $\hat{g}$, and $\hat{G}^-$ are asymptotically normally distributed with known variances and covariances:

$$\sigma_q^2 = PQ/N_1 \quad , \quad \sigma_{\hat{g}}^2 = g_o(1 - g_o)/N_2 \quad , \quad \sigma_{\hat{G}^-}^2 = G^-(1 - G^-)/N_2 \quad ,$$

$$\sigma_{q\hat{g}} = 0 \quad , \quad \sigma_{q\hat{G}^-} = 0 \quad , \quad \sigma_{\hat{g}\hat{G}^-} = - g_o G^-/N_2 \quad .$$

Now

$$dy'' = \frac{dq}{\hat{g}} - \frac{d\hat{G}^-}{\hat{g}} - \frac{q - \hat{G}^-}{\hat{g}^2} d\hat{g} \quad .$$

By the delta method, we obtain finally

$$\text{Var } y'' \cong \frac{1}{g_o^2}\left[\text{Var } q + \text{Var } \hat{G}^- + \left(\frac{Q - G^-}{g_o}\right)^2 \text{Var } \hat{g} + 2\,\frac{Q - G^-}{g_o}\,\text{Cov}\,(\hat{g},\hat{G}^-)\right]$$

$$= \frac{PQ}{N_1 g_o^2} + \frac{1}{N_2 g_o^2}\left[G^- - Q^2 + \frac{(Q - G^-)^2}{g_o}\right]$$

$$= \frac{1}{g_o^2}\left[\frac{PQ}{N_1} + \frac{PQ}{N_2} - \frac{1}{N_2}\cdot\frac{(G_o - Q)(Q - G^-)}{(G_o - G^-)}\right] \qquad (10)$$

where $G^- \equiv G_o - g_o$. Note that the last fraction in (10) approaches zero as $g_o \to 0$. Thus as g_o becomes small, (10) approaches (8), the variance for the continuous case.

3. Discrete Case, One Group

If there were no practice or fatigue effect, it would be more efficient to administer both tests to the same students. In order to see how much difference this would make, we derive the sampling variance of (9) for this case.

Let a , b , c , d , k , m be sample frequencies as defined by the accompanying diagram and let α , β , γ , δ , κ , and μ be the corresponding population

	$x < x_o$	$x > x_o$
$y > y_o$	b	a
$y = y_o$	k	m
$y < y_o$	d	c

proportions. In the present notation $q \equiv b + k + d$, $\hat{G} \equiv c + d$, and $\hat{g} \equiv k + m$, so (9) becomes

$$y'' = y' - 0.5 + \frac{b + k - c}{k + m} \quad . \tag{11}$$

The sample frequencies are again asymptotically multivariate normal with the familiar variances and covariances: $\sigma_b^2 = \beta(1 - \beta)/N$ $\sigma_{bc} = -\beta\gamma/N$, and so forth.

As before,

$$dy'' = \frac{db + dc}{k + m} + \frac{m - b + c}{(k + m)^2}\, dk - \frac{k + b - c}{(k + m)^2}\, dm \quad .$$

Using the delta method, we finally obtain after some algebra

$$\text{Var } y'' = \frac{1}{Ng_o^3}\left[\mu\kappa + (\beta + \gamma)g_o + (\beta - \gamma)^2\right] \tag{12}$$

where $g_o \equiv \mu + \kappa$.

If x and y are independently distributed, (12) becomes the same as (10) with $N_1 = N_2 = N$.

4. Continuous Case, One Group

When x and y are continuous, we deal with sample frequencies a, b, c, d, as defined in the accompanying diagram. The corresponding population proportions are denoted by α, β, γ, δ; for example $\delta = \Phi(x_o, y')$ where $\Phi(x,y)$ is the cumulative distribution function of x and y.

	$x < x_o$	$x > x_o$
$y > y'$	b	a
$y < y'$	d	c

Since y' is to be the q-th order statistic, as in section 1, where $q \equiv b + d$, it follows that given x_o, y' must always be chosen so that $b = c$. For given x_o, then, the frequency distribution of y' is proportional to the probability of finding one person at y', c persons with $x < x_o$ and $y > y'$, and c persons with $x > x_o$ and $y < y'$. Writing $M \equiv N - 1$, this probability is proportional to $g(y')$ times the sum, over all possible values of c, of the multinormal probability

$$\frac{M!\ \beta^c \beta^c (\alpha + \delta)^{M-2c}}{c!\ c!\ (M - 2c)!} \quad . \tag{13}$$

Using Stirling's approximation to the factorials, the distribution of y' for M even is

$$g(y') \sum_{c=o}^{M/2} \frac{M^{M+\frac{1}{2}} \beta^c \gamma^c (1 - \beta - \gamma)^{M-2c}}{2\pi c^{2c+1} (M - 2c)^{M-2c+\frac{1}{2}}} \tag{14}$$

Taking logs under the summation sign, we have that the asymptotic distribution of y' is proportional to

$$\sum_{c=o}^{M/2} \exp(\log A)$$

where

$$\log A \equiv \log g(y') - \tfrac{1}{2} \log(1 - 2C) - \log 2\pi - \log M - \log C$$

$$+ M[C \log \beta\gamma + (1 - 2C) \log(1 - \beta - \gamma) - 2C \log C$$

$$- (1 - 2C) \log(1 - 2C)]$$

where $C \equiv c/N$.

Expand A in powers of $\tilde{y} \equiv y' - y_o$ and $\tilde{c} \equiv C - \gamma_o$. Using a zero subscript to denote quantities evaluated at y_o (note that $\beta_o \equiv \gamma_o$, but that $d\beta/dy_o \neq d\gamma/dy_o$) and dropping terms of lower order than M , we find

$$\log A \doteq - \frac{M}{2\gamma_o(1 - 2\gamma_o)} [\tfrac{1}{2} \{(2\gamma_o' - g_o)^2 + g_o^2(1 - 2\gamma_o) \tilde{y}^2$$

$$- 2(2\gamma_o' - g_o) \tilde{y}\tilde{c} + 2\tilde{c}^2] \tag{15}$$

where $\gamma_o' \equiv d\gamma_o/dy_o$.

As in Feller (1950, Section VII.2), we see from (15) that c and y' are asymptotically bivariate normal. Writing $\lambda \equiv 1 - 2\gamma_o$, and $h \equiv 2\gamma_o' - g_o$, we see from (15) that

$$M\sigma_{y'}^2(1 - \rho^2) \doteq \frac{2\gamma_o\lambda}{h^2 + g_o^2\lambda} \quad , \tag{16}$$

$$M\sigma_c^2(1 - \rho^2) \doteq \frac{\gamma_o\lambda}{2} \quad , \tag{17}$$

$$\frac{M_0}{(1 - \rho^2)\sigma_{y'}\sigma_c} \doteq \frac{h}{\gamma_o\lambda} \quad , \tag{18}$$

where ρ is the correlation between y' and c. Squaring the last equation and multiplying by the other two, we find that

$$\rho^2 \doteq \frac{h^2}{h^2 + g_o^2\lambda} \quad , \quad 1 - \rho^2 \doteq \frac{g_o^2\lambda}{h^2 + g_o^2\lambda} \quad . \tag{19}$$

Thus finally, from (16) and (19),

$$\sigma_{y'}^2 \doteq \frac{2\gamma_o}{Ng_o^2} \quad . \tag{20}$$

Note that as the correlation between x and y approaches 1.0, the proportion γ_o approaches zero and $\sigma_{y'}^2$, in (20) vanishes. We may also see that in (12) when $\kappa + \mu \equiv g_o$ becomes small so that $\beta \to \gamma$, Var y'' for the discrete case with one group approaches (20).

When the correlation between x and y is zero, (20) is the same as (8) with $N_1 = N_2$.

5. Numerical Results

Formulas (8) and (20) for the continuous case are simpler than formulas (10) and (12) for the discrete case. We will give first some numerical results from formulas (8) and (20).

A Monte Carlo study was carried out by drawing $N = 1000$ pairs of pseudo-random standardized normal bivariate deviates (x,y) from a population with a correlation of $\rho_{xy} = .90$ (this is a typical correlation between parallel test forms). From this sample of 1000 cases the equated value of y' was found separately for $x_o = 0, 0.5, 1.0, 1.5, 2.0, 2.5$. The foregoing was repeated 1000 times with independently drawn bivariate samples. For each given x_o, the empirical standard deviation $s_{y'}$ was computed.

The resulting standard errors (not variances) are presented in the fourth column of Table 1. The corresponding theoretical values from (20) are shown in the third column. There is excellent agreement between theoretical and Monte Carlo results.

The second column of Table 1 shows the standard error, according to (8), when tests X and Y are administered to different examinees rather than to the same examinees. We see that this does not entail as serious a loss of equating accuracy as might have been feared. In view of the likelihood of practice and fatigue effects, it seems that the methods of Sections 1 and 2 should be used whenever possible, rather than the methods of Sections 3 and 4.

Table 1

Standard Errors of Equipercentile Equating for Normally Distributed Variables

	Standard Error		
	Eq. (8) [or (20), $\rho_{xy}=0$]	$\rho_{xy} = .90$	
x_o	$N_1 = N_2 = 1000$	Eq. (20)	Monte Carlo
0	.056	.030	.029
.5	.059	.032	.032
1.0	.068	.038	.037
1.5	.086	.052	.053
2.0	.124	.080	.079
2.5	.200	.138	.137

For illustrative purposes, Table 2 shows the standard errors of an equating of a 50-item M (Metropolitan Achievement Test) Word Analysis test to a 40-item C (Comprehensive Test of Basic Skills) Reading Vocabulary test. The data were drawn from the Anchor Test Study (Loret, Seder, Bianchini, and Vale, 1974) in which both tests were administered to a group of 1406 sixth-grade students. The resulting bivariate distribution of number-right scores was smoothed by a method described by Lord (1980, Section 17.4). The correlation between M and C was .88. The tabled values were computed from (12), ignoring the smoothing.

The standard deviation of number-right M scores for this group of sixth graders is 11.5. The standard error of measurement for M scores is 2.7. The standard error of equating is much smaller than the standard error of measurement.

Table 3 provides an empirical comparison between equipercentile equating and conventional linear equating. In this case, Form VSA4 of the 90-item SAT Verbal test had been administered to 2665 students, along with an 'anchor test' of 40 verbal items. At a later time, a new, 85-item Verbal form, XSA2, was similarly administered along with the same anchor test to a new group of 2686 students. As part of normal scoring and reporting, Form XSA2 raw ('formula') scores were equated by a standard linear method due to L. R Tucker (Angoff, 1971, Equating Design IV.A.) to the scaled scores on Form VSA4. This equating is shown along with its standard error as determined by the computer program AUTEST (Lord, 1975), in the first three columns of Table 3.

Table 2

Standard Error of Equipercentile Equating, Number-Right Scores,

MAT to CTBS

C Scores	Cumulative Frequency Distribution	Equated M Scores	Standard Error of Equating
37.5	.98	49.3	.17
32.5	.89	45.8	.20
27.5	.76	42.1	.22
22.5	.61	37.6	.26
17.5	.44	31.9	.32
12.5	.26	23.1	.44
7.5	.08	13.8	.36
2.5	.01	8.8	.44

Table 3

Comparison of Linear and Equipercentile Equating for the Verbal Score on Form XSA2, College Board Scholastic Aptitude Test

	Linear (Tucker) Model		Equipercentile Method	
XSA2 formula score	Equivalent scaled score	Standard error	Equivalent scaled score	Standard error
78.1	738	4.07	774	13.47
70.6	685	3.46	722	15.85
64.75	644	3.00	652	10.32
58.9	602	2.56	602	4.97
52.9	559	2.15	558	4.12
47.25	519	1.82	514	3.47
40.1	469	1.54	466	3.44
32.4	414	1.51	417	2.93
25.75	367	1.72	364	3.37
16.1	298	2.28	314	4.07
7.6	238	2.90	242	5.70
-3.75	157	3.80	195	7.85

The equipercentile equating of XSA2 to VSA4 was effected by equating each test to the anchor test independently and then using the rule that scores equated to the same anchor-test score are equated to each other. Thus the equipercentile equating of XSA2 to VSA4 requires two independent equatings of the type treated in Section 3 of this paper. The sampling variances (12) of the two equatings are additive, since they are computed from two different samples of students. The resulting equipercentile equating and standard error are shown in the last two columns of the table.

To put these standard errors into perspective, note that the standard deviation of scaled scores in a group of students is typically about 100. The standard error of measurement of a scaled score is about 30 to 33. The standard errors of equating are mostly small by comparison. The standard errors of the equipercentile equating are double those of the linear equating in the middle of the score range, comparatively larger at the extremes.

Equipercentile equating can be improved by smoothing the empirical frequency distribution of scores before equating. This reduces the sampling errors but may introduce small biases that do not disappear even in very large samples. The sampling error of a smoothed equating could perhaps be determined for a specified smoothing method, but the mathematics would be burdensome.

References

Angoff, W. H. Scales, norms, and equivalent scores. In R. L. Thorndike (Ed.), Educational measurement (2nd ed.). Washington, D.C.: American Council on Education, 1971. Pp. 508-600.

Kendall, M. G. & Stuart, A. The advanced theory of statistics (Vol. 1, 3rd ed.). New York: Hafner, 1969.

Lord, F. M. Automated hypothesis tests and standard errors for non-standard problems. The American Statistician, 1975, 29, 56-59.

Lord, F. M. Applications of item response theory to practical testing problems. Hillsdale, N.J.: Lawrence Erlbaum Associates, 1980.

Loret, P. G., Seder, A., Bianchini, J. C., & Vale, C. A. Anchor Test Study - Equivalence and norms tables for selected reading achievement tests (grades 4, 5, 6). Washington, D.C.: U.S. Government Printing Office, 1974.

DISTRIBUTION LIST

Navy

1 Dr. Ed Aiken
Navy Personnel R & D Center
San Diego, CA 92152

1 Dr. Jack R. Borsting
Provost and Academic Dean
U.S. Naval Postgraduate School
Monterey, CA 93940

1 Dr. Robert Breaux
Code N-711
NAVTRAEQUIPCEN
Orlando, FL 32813

1 Chief of Naval Education and
Training Liason Office
Air Force Human Resource Laboratory
Flying Training Division
Williams Air Force Base, AZ 85224

1 CDR Mike Curran
Office of Naval Research
800 North Quincy Street
Code 270
Arlington, VA 22217

1 Dr. Richard Elster
Department of Administrative Sciences
Naval Postgraduate School
Monterey, CA 93940

1 Dr. Pat Federico
Navy Personnel R & D Center
San Diego, CA 92152

1 Mr. Paul Foley
Navy Personnel R & D Center
San Diego, CA 92152

1 Dr. John Ford
Navy Personnel R & D Center
San Diego, CA 92152

1 Dr. Patrick R. Harrison
Psychology Course Director
Leadership and Law Department (7b)
Division of Professional Development
U.S. Naval Academy
Annapolis, MD 21402

1 Dr. Norman J. Kerr
Chief of Naval Technical Training
Naval Air Station Memphis (75)
Millington, TN 38054

1 Dr. William L. Maloy
Principal Civilian Advisor for
Education and Training
Naval Training Command, Code 00A
Pensacola, FL 32508

1 Dr. Kneale Marshall
Scientific Advisor to DCNO(MPT)
Op01T
Washington, DC 20370

1 Dr. James McBride
Navy Personnel R & D Center
San Diego, CA 92152

1 Dr. William Montague
Navy Personnel R & D Center
San Diego, CA 92152

1 Mr. William Nordbrock
Instructional Program Development
Building 90
NET-PDCD
Great Lakes NTC, IL 60088

1 Library, Code P201L
Navy Personnel R & D Center
San Diego, CA 92152

1 Technical Director
Navy Personnel R & D
San Diego, CA 92152

6 Commanding Officer
Naval Research Laboratory
Code 2627
Washington, DC 20390

1 Psychologist
ONR Branch Office
Building 114, Section D
666 Summer Street
Boston, MA 02210

1 Office of Naval Research
Code 437
800 North Quincy Street
Arlington, VA 22217

5 Personnel and Training Research Programs
Code 458
Office of Naval Research
Arlington, VA 22217

1 Psychologist
ONR Branch Office
1030 East Green Street
Pasadena, CA 91101

1 Office of the Chief of Naval Operations
Research Development and Studies Branch
OP-115
Washington, DC 20350

1 LT Frank C. Petho, MSC, USN (Ph.D.)
Selection and Training Research Division
Human Performance Sciences Department
Naval Aerospace Medical Research Lab.
Pensacola, FL 32508

1 Dr. Bernard Rimland (03B)
Navy Personnel R & D Center
San Diego, CA 92152

1 Mr. Arnold Rubenstein
Office of Naval Technology
800 N. Quincy Street
Arlington, VA 22217

1 Dr. Worth Scanland, Director
Research, Development, Test and Evaluation
N-5
Naval Education and Training Command
NAS
Pensacola, FL 32508

1 Dr. Robert G. Smith
Office of Chief of Naval Operations
OP-987H
Washington, DC 20350

1 Dr. Alfred F. Smode
Training Analysis and Evaluation Group
Department of the Navy
Orlando, FL 32813

1 Dr. Richard Sorensen
Navy Personnel R & D Center
San Diego, CA 92152

1 Mr. J. B. Sympson
Naval Personnel R & D Center
San Diego, CA 92152

1 Dr. Ronald Weitzman
Code 54 WZ
Department of Administrative Services
U.S. Naval Postgraduate School
Monterey, CA 93940

1 Dr. Robert Wherry
562 Mallard Drive
Chalfont, PA 18914

1 Dr. Robert Wisher
Code 309
Navy Personnel R & D Center
San Diego, CA 92152

1 Dr. Martin F. Wiskoff
Navy Personnel R & D Center
San Diego, CA 92152

1 Mr. Ted M. I. Yellen
Technical Information Office
Code 201
Navy Personnel R & D Center
San Diego, CA 92152

Army

1 Technical Director
U.S. Army Research Institute for the
Behavioral and Social Sciences
5001 Eisenhower Avenue
Alexandria, VA 22333

1 Dr. Myron Fischl
U.S. Army Research Institute for the
Social and Behavioral Sciences
5001 Eisenhower Avenue
Alexandria, VA 22333

1 Dr. Dexter Fletcher
U.S. Army Research Institute
5001 Eisenhower Avenue
Alexandria, VA 22333

1 COL Frank Hart
Army Research Institute for the
Behavioral & Social Sciences
5001 Eisenhower Blvd.
Alexandria, VA 22333

1 Dr. Michael Kaplan
U.S. Army Research Institute
5001 Eisenhower Avenue
Alexandria, VA 22333

1 Dr. Milton S. Katz
Training Technical Area
U.S. Army Research Institute
5001 Eisenhower Avenue
Alexandria, VA 22333

1 Dr. Harold F. O'Neil, Jr.
Attn: PERI-OK
Army Research Institute
5001 Eisenhower Avenue
Alexandria, VA 22333

1 Dr. Robert Sasmor
U.S. Army Research Institute for
the Social and Behavioral Sciences
5001 Eisenhower Avenue
Alexandria, VA 22333

1 Commandant
U.S. Army Institute of Administration
Attn: Dr. Sherrill
Ft. Benjamin Harrison, IN 46256

1 Dr. Frederick Steinheiser
Department of the Navy
Chief of Naval Operations
OP-113
Washington, DC 20350

1 Dr. Joseph Ward
U.S. Army Research Institute
5001 Eisenhower Avenue
Alexandria, VA 22333

Air Force

1 Air Force Human Resources Laboratory
AFHRL/MPD
Brooks Air Force Base, TX 78235

1 U.S. Air Force Office of
Scientific Research
Life Sciences Directorate
Bolling Air Force Base
Washington, DC 20332

1 Air University Library
AUL/LSE 76/443
Maxwell Air Force Base, AL 36112

1 Dr. Earl A. Alluisi
HQ, AFHRL (AFSC)
Brooks Air Force Base, TX 78235

1 Mr. Raymond E. Christal
AFHRL/MO
Brooks Air Force Base, TX 78235

1 Dr. Genevieve Haddad
Program Manager
Life Sciences Directorate
AFOSR
Bolling Air Force Base
Washington, DC 20332

1 Dr. Ross L. Morgan
AFHRL/LR
Wright-Patterson AFB, OH 45433

1 Research and Measurement Division
Research Branch, AFMPC/MPCYPR
Randolph Air Force Base, TX 78148

1 Dr. Malcolm Ree
AFHRL/MP
Brooks Air Force Base, TX 78235

1 Dr. Marty Rockway
Technical Director
AFHRL(OT)
Williams Air Force Base, AZ 58224

Marines

1 Dr. H. William Greenup
Education Advisor (E031)
Education Center, MCDEC
Quantico, VA 22134

1 Director, Office of Manpower Utilization
HQ, Marine Corps (MPU)
BCB, Building 2009
Quantico, VA 22134

1 MAJ Michael L. Patrow, USMC
Headquarters, Marine Corps
Code MPI-20
Washington, DC 20380

1 Dr. A. L. Slafkosky
Scientific Advisor
Code RD-1
HQ, U.S. Marine Corps
Washington, DC 20380

Coast Guard

1 Mr. Thomas A. Warm
U.S. Coast Guard Institute
P.O. Substation 18
Oklahoma City, OK 73169

Other DoD

1 DARPA
1400 Wilson Boulevard
Arlington, VA 22209

12 Defense Technical Information Center
Cameron Station, Building 5
Attn: TC
Alexandria, VA 22314

1 Dr. William Graham
Testing Directorate
MEPCOM/MEPCT-P
Ft. Sheridan, IL 60037

1 Military Assistant for Training
and Personnel Technology
Office of the Under Secretary of
Defense for Research and Engineering
Room 3D129, The Pentagon
Washington, DC 20301

1 Dr. Wayne Sellman
Office of the Assistant Secretary
of Defense (MRAL)
2B2o9 The Pentagon
Washington, DC 20301

Civil Government

1 Dr. Susan Chipman
Learning and Development
National Institute of Education
1200 19th Street, NW
Washington, DC 20208

1 Mr. Richard McKillip
Personnel R & D Center
Office of Personnel Management
1900 E Street, NW
Washington, DC 20415

1 Dr. Arthur Melmed
National Institute of Education
1200 19th Street, N.W.
Washington, DC 20208

1 Dr. Andrew R. Molnar
Science Education Development
and Research
National Science Foundation
Washington, DC 20550

1 Dr. Vern W. Urry
Personnel R & D Center
Office of Personnel Management
1900 E Street, NW
Washington, DC 20415

1 Dr. Joseph L. Young, Director
Memory and Cognitive Processes
National Science Foundation
Washington, DC 20550

Non-Government

1 Dr. Erling B. Andersen
Department of Statistics
Studiestraede 6
1455 Copenhagen
DENMARK

1 Psychological Research Unit
Department of Defense (Army Office)
Campbell Park Offices
Canberra, ACT 2600
AUSTRALIA

1 Dr. Alan Baddeley
Medical reserch Council
Applied Psychology Unit
15 Chaucer Road
Cambridge CB2 2EF
ENGLAND

1 Dr. Isaac Bejar
Educational Testing Service
Princeton, NJ 08541

1 Dr. Menucha Birenbaum
School of Education
Tel Aviv University
Tel Aviv, Ramat Aviv 69978
ISRAEL

1 Dr. Werner Birke
DezWPs im Streitkraefteamt
Postfach 20 50 3
D-5300 Bonn 2
WEST GERMANY

1 Dr. R. Darrell Bock
Department of Education
University of Chicago
Chicago, IL 60637

1 Liaison Scientists
Office of Naval Research
Branch Office, London
Box 39
FPO, NY 09510

1 Dr. Robert Brennan
American College Testing Programs
P.O. Box 168
Iowa City, IA 52240

1 Dr. John B. Carroll
Psychometric Laboratory
University of North Carolina
Davie Hall 013A
Chapel Hill, NC 27514

1 Charles Myers Library
Livingstone House
Livingstone Road
Stratford
London E15 2LJ
ENGLAND

1 Dr. Kenneth E. Clark
College of Arts and Sciences
University of Rochester
River Campus Station
Rochester, NY 14627

1 Dr. Norman Cliff
Department of Psychology
University of Southern California
University Park
Los Angeles, CA 90007

1 Dr. William E. Coffman
Director, Iowa Testing Programs
334 Lindquist Center
University of Iowa
Iowa City, IA 52242

1 Dr. Allan M. Collins
Bolt, Beranek, & Newman, Inc.
50 Moulton Street
Cambridge, MA 02138

1 Dr. Meredith P. Crawford
American Psychological Association
1200 17th Street, N
Washington, DC 20036

1 Dr. Hans Crombag
Education Research Center
University of Leyden
Boerhaavelaan 2
2334 EN Leyden
THE NETHERLANDS

1 Dr. Fritz Drasgow
Yale School of Organization and
Management
Yale University
Box 1A
New Haven, CT 06520

1 LCOL J. C. Eggenberger
Directorate of Personnel
Applied Research
National Defence Hq.
101 Colonel By Drive
Ottawa, KIA 0K2
CANADA

1 Dr. Benjamin A. Fairbank, Jr.
McFann-Gray and Associates, Inc.
5825 Callaghan
Suite 225
San Antonio, TX 78228

1 Dr. Leonard Feldt
Lindquist Center for Measurement
University of Iowa
Iowa City, IA 52242

1 Dr. Richard L. Ferguson
The American College Testing Program
P.O. Box 168
Iowa City, IA 52240

1 Dr. Victor Fields
Department of Psychology
Montgomery College
Rockville, MD 20850

1 Univ. Prof. Dr. Gerhard Fischer
Psychologisches Institut der
Universitat Wien
Liebiggasse 5/3
A 1010 Wien
AUSTRIA

1 Prof. Donald Fitzgerald
University of New England
Armidale, New South Wales 2351
AUSTRALIA

1 Dr. Edwin A. Fleishman
Advanced Research Resources Organization
Suite 900
4330 East West Highway
Washington, DC 20014

1 Dr. John R. Frederiksen
Bolt, Beranek, and Newman
50 Moulton Street
Cambridge, MA 02138

1 Dr. Robert Glaser
LRDC
University of Pittsburgh
3939 O'Hara Street
Pittsburgh, PA 15213

1 Dr. Bert Green
Department of Psychology
Johns Hopkins University
Charles and 34th Streets
Baltimore, MD 21218

1 Dr. Ron Hambleton
School of Education
University of Massachusetts
Amherst, MA 01002

1 Dr. Lloyd Humphreys
Department of Psychology
University of Illinois
Champaign, IL 61820

1 Library
HumRRO/Western Division
27857 Berwick Drive
Carmel, CA 93921

1 Dr. Steven Hunka
Department of Education
University of Alberta
Edmonton, Alberta
CANADA

1 Dr. Earl Hunt
Department of Psychology
University of Washington
Seattle, WA 98105

1 Dr. Jack Hunter
2122 Coolidge Street
Lansing, MI 48906

1 Dr. Huynh Huynh
College of Education
University of South Carolina
Columbia, SC 29208

1 Mr. Marlin Kroger
1117 Via Goleta
Palos Verdes Estates, CA 90274

1 Dr. Michael Levine
Department of Educational Psychology
210 Education Building
University of Illinois
Champaign, IL 61801

1 Dr. Charles Lewis
Faculteit Sociale Wetenschappen
Rijksuniversiteit Groningen
Oude Boteringestraat 23
9712GC Groningen
NETHERLANDS

1 Dr. Robert Linn
College of Education
University of Illinois
Urbana, IL 61801

1 Dr. James Lumsden
Department of Psychology
University of Western Australia
Nedlands, Western Australia 6009
AUSTRALIA

1 Dr. Gary Marco
Educational Testing Service
Princeton, NJ 08541

1 Dr. Scott Maxwell
Department of Psychology
University of Houston
Houston, TX 77004

1 Dr. Samuel T. Mayo
Loyola University of Chicago
820 North Michigan Avenue
Chicago, IL 60611

1 Dr. Allen Munro
Behavioral Technology Laboratories
1845 Elena Avenue
Fourth Floor
Redondo Beach, CA 90277

1 Dr. Melvin R. Novick
356 Lindquist Center for Measurement
University of Iowa
Iowa City, IA 52242

1 Dr. Jesse Orlansky
Institute for Defense Analyses
400 Army Navy Drive
Arlington, VA 22202

1 Dr. Wayne M. Patience
American Council on Education
GED Testing Service, Suite 20
One Dupont Circle, NW
Washington, DC 20036

1 Dr. James A. Paulson
Portland State University
P.O. Box 751
Portland, OR 97207

1 Mr. Luigi Petrullo
2431 North Edgewood Street
Arlington, VA 22207

1 Dr. Diane M. Ramsey-Klee
R-K Research and System Design
3947 Ridgemont Drive
Malibu, CA 90265

1 Mr. Minrat M. L. Rauch
P II 4
Bundesministerium der Verteidigung
Postfach 1328
D-53 Bonn 1
GERMANY

1 Dr. Mark D. Reckase
Educational Psychology Department
University of Missouri-Columbia
4 Hill Hall
Columbia, MO 65211

1 Dr. Leonard L. Rosenbaum, Chairman
Department of Psychology
Montgomery College
Rockville, MD 20850

1 Dr. Ernst Z. Rothkopf
Bell Laboratories
600 Mountain Avenue
Murray Hill, NJ 07974

1 Dr. Lawrence Rudner
403 Elm Avenue
Takoma Park, MD 20012

1 Dr. J. Ryan
Department of Education
University of South Carolina
Columbia, SC 29208

1 Prof. Fumiko Samejima
Department of Psychology
University of Tennessee
Knoxville, TN 37916

1 Dr. Frank L. Schmidt
Ddepartment of Psychology
Building GG
George Washington University
Washington, DC 20052

1 Dr. Robert J. Seidel
Instructional Technology Group
HumRRO
300 North Washington Street
Alexandria, VA 22314

1 Committee on Cognitive Research
c/o Dr. Lonnie R. Sherrod
Social Science Research Council
605 Third Avenue
New York, NY 10016

1 Dr. Kazuo Shigemasu
University of Tohoku
Department of Educational Psychology
Kawauchi, Sendai 980
JAPAN

1 Dr. Edwin Shirkey
Department of Psychology
University of Central Florida
Orlando, FL 32816

1 Dr. Richard Snow
School of Education
Stanford University
Stanford, CA 94305

1 Dr. Robert Sternberg
Department of Psychology
Yale University
Box 11A, Yale Station
New Haven, CT 06520

1 Dr. Albert Stevens
Bolt, Beranek, and Newman, Inc.
50 Moulton Street
Cambridge, MA 02138

1 Dr. Hariharan Swaminathan
Laboratory of Psychometric and
Evaluation Research
School of Education
University of Massacuusetts
Amherst, MA 01003

1 Dr. Kikumi Tatsuoka
Computer Based Education Research
Laboratory
252 Engineering Research Laboratory
University of Illinois
Urbana, IL 61801

1 Dr. David Thissen
Department of Psychology
University of Kansas
Lawrence, KS 66044

1 Dr. Robert Tsutakawa
Department of Statistics
University of Missouri
Columbia, MO 65201

1 Dr. David Vale
Assessment Systems
Corporation
2395 University Avenue
Suite 306
St. Paul, MN 55114

1 Dr. Howard Wainer
Educational Testing Service
Princeton, NJ 08541

1 Dr. Thomas Wallsten
Psychometric Laboratory
Davie Hall 013A
University of North Carolina
Chapel Hill, NC 27514

1 Dr. Phyllis Weaver
Graduate School of Education
Harvard University
200 Larsen Hall, Appian Way
Cambridge, MA 02138

1 Dr. David J. Weiss
N660 Elliott Hall
University of Minnesota
75 East River Road
Minneapolis, MN 55455

1 Dr. Susan E. Whitely
Psychology Department
University of Kansas
Lawrence, KS 66044

1 Dr. Wolfgang Wildgrube
Streitkraefteamt
Box 20 50 03
D-5300 Bonn 2
WEST GERMANY